National Park Service
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Natural Resource Stewardship and Science

Excellent Science in the National Park Service Inventory and Monitoring Division

Guiding Principles and Recommendations

Natural Resource Report NPS/WASO/NRR—2016/1217

ON THE COVER

Ecologists at work in (from top left) the National Capital Region, Sonoran Desert, Chihuahan Desert, Great Lakes, and Northern Colorado Plateau (inset) networks. NPS photos.

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

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Contents

Acronyms

I&M	Inventory & Monitoring
IRMA	Integrated Resource Management Applications
NGO	non-governmental organization
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRPS	Natural Resources Publication Series
NRR	Natural Resource Report
NRSS	Natural Resource Stewardship and Science directorate
RGE	research grade evaluation
SNOTEL	snow telemetry
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WASO	Washington Area Service Office

This document is dedicated to Daniel Sarr, 1964–2015.

Daniel was perceptive, articulate, intelligent, dedicated, humorous, and a passionate advocate for science. While program manager for the Klamath Network, he always pushed the Inventory and Monitoring Division to use science to enrich our understanding of the world and enhance and support management actions, and sought to link I&M work with other scientific entities outside the National Park Service. We hope that Daniel would be proud of this document and its recommendations.

Acknowledgements

We would like to thank I&M leadership for allowing this document to be written and considering our ideas for moving the program forward. We would also like to thank the employees who conceived, developed, answered, and compiled the I&M survey (see Preface). Without the survey, this workgroup and report would not have come to be. Stories of success from those conducting excellent science around the program continue to inspire us. Lastly, we would like to thank Joe DeVivo, Brian Gregory, Mark Huff, Matt Marshall, Tom Rodhouse, Suzanne Sanders, John Paul Schmit, Joshua Schmidt, and Mike Story for their thoughtful review. Their comments have greatly improved this report.

Preface: The Excellence in Science Committee

The Excellence in Science Committee was formed in January 2014, at an Inventory and Monitoring Division Leadership Team Meeting in Omaha, Nebraska. At that time, the Inventory and Monitoring (I&M) program in the National Park Service was over 10 years old and transitioning from a start-up program to one of science delivery and resource management support. In those first 10 years, much was learned by the 32 I&M networks (referred to as the "32 experiments") about environmental monitoring, science delivery, and science communication. These different experiences provided clear insights about how to integrate a monitoring program into a science agency as complex as that of the National Park Service.

To see that information parlayed into useful science information for decision making, former division chief Bruce Bingham initiated a survey of all I&M employees, tapping into the collective wisdom, experiences, and expertise of staff to (1) get their input into what was working with the I&M program and (2) identify where improvements can be made to the science support that the program delivers to our national parks and monuments. Andy (John) Hubbard (later acting division chief), and Kirsten Gallo (acting deputy chief) worked with Marianne Tucker to compile the survey results and initiate discussions in Omaha about how to channel that collective wisdom and experience into productive outcomes for the program.

The goal: to create a lasting, tangible impact on park management using I&M science as its foundation. Promulgated from those discussions was the creation of four committees: Excellence in Science, Science Communication, Inventories, and Accountability and Achievability. Of these, the Excellence in Science Committee was subdivided into three workgroups, each asked to address different dimensions of how to create and deliver excellent science to NPS via the Inventory and Monitoring Program:

- The Stellar Science Committee, chaired by Northern Colorado Plateau Network Program Manager Dusty Perkins, was tasked with defining what Excellent Science means in the context of the National Park Service. Their task was to bridge the gap between traditional views of excellence as defined by peer-reviewable science and the application of science so that it effectively informs managers of resource agencies of the status and trends of resources at their respective parks.
- The Integrating Science and Management workgroup, chaired by Southern Plains Network Program Manager Robert Bennetts, was assigned to evaluate approaches to effectively integrate I&M science into parks and proposing methods to improve science delivery and use in science-based management decisions.
- The Attracting, Developing, and Retaining Excellent Science and Staff workgroup, chaired by Appalachian Highlands Network Program Manager Brian Witcher, sought to identify how we can attract, train, and retain scientists and technical staff in the program, identify what makes a successful monitoring network, and what training can be provided to improve skills within the program.

Each workgroup was asked to explore the dimensions of their respective science-transfer responsibilities to NPS and develop recommendations to improve that delivery.

In these efforts, we are indebted to Steve Fancy, Bruce Bingham (both influential former division chiefs), and all I&M employees and contractors, park resources staff, and superintendents for their dedication in helping bring science into how we manage parks for the American people and the world.

—Michael Bozek
Chair, Excellence in Science Committee

Introduction

Background

The National Park Service (NPS) manages some of the nation's most spectacular natural landscapes, along with extraordinary historical and cultural resources. Effective stewardship of these resources is a science-based endeavor (NPS 2012) that requires excellent, place-based science (Billick and Price 2010). The term "place-based" describes science that is place-specific and designed to reveal place-specific relationships in support of conservation (Williams et al. 2013). In our case, "place" encompasses the units of the National Park System. Place-based science relies on in-depth understanding of diverse ecosystems, including the function of, and relationships among, specific physical and biotic components and the human interactions affecting them.

Science designed for the purpose of monitoring the condition and changes of national park resources is crucial to effective resource stewardship efforts. The overarching goal of the NPS's Inventory and Monitoring (I&M) Division is to use excellent science to monitor vital natural resources, with the goal of improving our understanding of long-term changes to resource condition and the drivers and stressors that affect it, and to provide park managers with that information. Timely delivery of this information to resource managers and other decision makers is crucial for effective park management, especially as the agency enters its second century. Today, the NPS and other natural resource agencies face unprecedented rates of environmental change, novel or unprecedented behaviors of ecosystems (i.e., ecological novelty), and anthropogenic pressures across the globe. I&M science must support myriad management decisions, anticipate and help mitigate negative consequences of change, and, ultimately, help promote policies ensuring that resources remain "*unimpaired for the enjoyment of future generations*" (National Park Service Organic Act).

Here we outline the guiding principles and scientific standards important to the success of the National Park Service via the I&M program and its scientists. This document serves as a reference for how I&M scientists can personally and programmatically attain excellence within the I&M program. We detail important aspects of how to be an effective scientist engaged in place-based monitoring of natural resources in national parks. We also highlight programmatic limitations and suggest how to remedy these challenges with effective and implementable recommendations. If implemented, these recommendations will enhance the program's capacity to deliver timely, credible, and useful science information for resource management decision making.

For the purposes of this document, "excellent science" within the I&M program refers to science that is carried out by highly trained and qualified individuals conducting well-designed, relevant, and reproducible investigations that address the complexities and uncertainties of real-world problems facing NPS managers.

Policy and Guidance: Setting the Stage

Broad directives

In 1997, the Natural Resources Challenge (NPS 2012) served as a call to action for a strong, agency-wide commitment to science as a platform for management action. In the following year, the U.S. Congress ordered the Secretary of the Interior to "undertake a program of inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources" (National Parks Omnibus Management Act of 1998). As a result, the I&M program was launched and long-term ecological monitoring was institutionalized within the agency. Through its 32 networks, the I&M program set out to select a parsimonious set of natural resource indicators, or "vital signs," and create scientifically credible protocols for monitoring them at sufficient resolution to detect natural variability and/or quantify change (Oakley et al. 2003; Fancy and Bennetts 2012; Sergeant et al. 2012).

The first element of building and maintaining any effective program is to ensure that all of its employees understand their fundamental mission. The following policy excerpts serve as cornerstones of the NPS I&M program.

The Natural Resources Inventory and Monitoring Guideline NPS-75, published in 1992 (NPS 1992), states:

> "The purpose of a natural resource ecological monitoring system is to provide a rational basis for taking management actions. Actions based on sound scientific data from monitoring will engender a higher level of confidence and will better ensure that natural resources and ecosystem functions remain unimpaired for future generations."

Fancy and others (2009) further stated:

> "The overall purpose of natural resource monitoring in parks is to develop scientifically sound information on the current status and long term trends in the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems."

Similar policy directives have been issued over the past two decades and are summarized in "Guidance for Designing an Integrated Monitoring Program" (NPS 2012). More recently, an external advisory board composed of recognized scholars wrote, in "Revisiting Leopold" (NPS Advisory Board 2012):

> "The need for science—to understand how park ecosystems function, monitor impacts of change (even from afar), inform decisions makers and their decisions, and enrich public appreciation of park values—has never been greater."

That report continues with recommendations for significantly expanding the role of science in the NPS to aid in resource management decision making. The NPS Advisory Board recommended that NPS "expand scientific capacity" and "train, equip, retain, and support the career advancement of these research scientists." Furthermore, the Board recommended that NPS scientists have "increased opportunities to interact with the scientific community, including professional associations, and specific responsibility and opportunity for publishing their work in the scientific literature."

Specific goals

NPS-75 (NPS 1992) identifies these specific goals for I&M:

- Inventory the natural resources under National Park Service stewardship to determine their nature and status.
- Monitor park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other, altered environments.
- Establish natural resource inventory and monitoring as a standard practice throughout the National Park System that transcends traditional program, activity, and funding boundaries.
- Integrate natural resource inventory and monitoring information into National Park Service planning, management, and decision making.
- Share National Park Service accomplishments and information with other natural resource organizations and form partnerships for attaining common goals and objectives.

Principles of an Excellent I&M Science Program

A principal strength of I&M is its collective of scientists with diverse scientific expertise working on common management issues (e.g., water quantity and quality, invasive plants) that were identified and documented using a comprehensive planning process across parks, networks, and nationally. That process coupled I&M scientists with park natural resource managers and superintendents who had on-the-ground knowledge of local resource management issues. This enables the program to design and implement place-based monitoring and reporting

systems to enhance the flow of scientific information from scientists to managers.

A potential weakness exists, however, if I&M science is not viewed as credible, or not vetted through external peer review. Furthermore, contemporary resource threats, such as escalating development within and outside parks, increasing visitation, and climate change, require the efficiency of science delivery to improve as increasing demands are placed on park managers. Finally, long-term vital signs monitoring, though selected and conducted through thoughtful deliberation, does not always provide managers with information they need for immediate, "hot" issues of the day.

Some of these weaknesses can be easily resolved. Others will require investment in changes that promote peer-reviewed publications, some flexibility to answer immediate management questions, and a culture of science embedded within a larger and much older culture of management. Below, we offer some basic principles for an excellent I&M science program (see box). These principles, some of which are already being well-met, assume that dedicated scientists, managers, technicians, and support staff are collectively executing well-designed investigations and producing defensible data and reports that are useful for resource managers. This science must be relevant, timely, adaptive, rigorously peer-reviewed, and should address any data limitations (NPS Advisory Board 2012). This will enable the I&M program to become the world's leader in stimulating, synthesizing, and utilizing place-based science that can be used to steward resources through continuous change across broad areas and long-time horizons.

Principles of an Excellent I&M Science Program

To produce and deliver excellent science, the I&M program must:

1. Understand the needs of park managers for natural resource information so that we may identify key questions and objectives, set reasonable monitoring goals, and ensure the usefulness of reporting and communication;
2. Ensure the scientific credibility, reliability, and integrity of the program by:
   - designing and implementing scientifically sound sampling protocols;
   - efficiently collecting valid, reproducible, and relevant data;
   - implementing strong data management, quality assurance, and control measures;
   - archiving data and information to ensure against data loss;
   - employing rigorous, state-of-the-science analyses to deliver credible interpretations;
   - encouraging publication in juried science literature;
   - holding employees accountable for the creation of credible and timely products; and
   - examining allegations of scientific misconduct and taking corrective action

   —all of which should ensure that our science holds up under both scientific and legal scrutiny;
3. Build science-based collegiality and collaboration across grade levels and organizational boundaries in order to stimulate creativity and productivity;
4. Build strong collaborations within the division and the agency, among other science and land management agencies, and with academic science partners to expand capacity and maintain relevance;
5. Provide employees with critical training and professional development opportunities that will aid recruitment and retention of quality staff and build credibility for the I&M science program;
6. Respond to technological improvements and changing environmental and management conditions with refined monitoring questions and new protocols, while retaining historical integrity of pre-existing efforts; and
7. Adopt a peer-review process scaled to meet the demands of timely briefs and juried scientific journals.

A Self-Assessment

The wisdom of the NPS approach for long-term monitoring is relatively simple: it combines practical, place-based knowledge from people local to the resource (park staff) with the scientific and technical expertise of I&M staff. The scientific information is then used to make management decisions as required by the National Parks Omnibus Management Act of 1998 (Public Law 105-391) (see box).

The National Parks Omnibus Management Act of 1998 (Public Law 105-391) states in Section 206, Integration of Study Results into Management Decisions:

"The Secretary shall take such measures as are necessary to assure the full and proper utilization of the results of scientific study for park management decisions."

"In each case in which an action undertaken by the National Park Service may cause a significant adverse effect on a park resource, the administrative record shall reflect the manner in which unit resource studies have been considered."

"The trend in the condition of resources of the National Park System shall be a significant factor in the annual performance evaluation of each superintendent of a unit of the National Park System."

From the outset, I&M leadership provided guidance and standards for establishment and growth of the program's 32 networks. These included charters describing the role of park superintendents and park resource management staff. The guidance also required that networks develop in three distinct phases, each with steps designed to ensure that they considered current knowledge and knowledge gaps, thought broadly through conceptual ecosystem models, and obtained expert opinion and buy-in by involving park staff and outside scientists.

This phased process ended with each network publishing a peer-reviewed monitoring plan and one or more peer-reviewed protocols. The process was deliberative, inclusive, and involved extensive review by scientists and other stakeholders within and outside the NPS. Built into this prescriptive framework was flexibility that allowed networks and their client parks to develop unique decision making structures, staffing plans, and monitoring protocols to meet park needs. This type of flexibility is an essential component for a successful long-term ecological monitoring program (Sergeant et al. 2012) with diverse ecological systems (e.g., alpine tundra, caves, coral reefs, deserts, grasslands, rivers, springs and seeps, temperate forests) extending from the Pacific Islands to Maine and from Alaska to the Caribbean Sea (Fancy and Bennetts 2012).

Since its inception, the I&M program and its employees have been recognized as reliable and credible sources of scientific information within the NPS. I&M data have been used to support numerous park management actions, such as writing environmental impact statements, listing and de-listing of 303(d) waters, locating new trails, developing seed mixtures, and providing extensive data to park Natural Resource Condition Assessments and State of the Park reports. Internally, the program has been judged a success (Gitzen and Millspaugh 2012; Fancy and Bennetts 2012; Sergeant et al. 2012; Fancy et al. 2009). However, there has not been a critical review of the I&M program from the scientific community at large. We believe this is an important next step for the I&M program.

Currently, I&M publishes 300–500 data summary and technical reports each year and makes them available to resource managers through the NPS Natural Resource Publication Series (NRPS). The I&M program implemented this report series in 2009, and I&M manages the peer-review, editing, archival, and web-access to these reports. Unfortunately, these reports are considered "grey literature" by the science community. While they are peer-reviewed, they are not juried under the strict anonymous peer-review standards of science journals.

The NPS report series is also not widely available through standard science literature searches. As a result, NPS science lacks visibility compared to that of other natural resource agencies (see table). Increasing visibility by encouraging publication in juried science literature would allow external scientists to both scrutinize and learn from NPS science and the decisions made from it (as

Membership and juried publication numbers of federal resource agencies.

Institution	Members	Publications	Publications/Member
U.S. Department of Agriculture	1,907	12,116	6.35
U.S. Geological Survey	2,060	6,721	3.26
U.S. Environmental Protection Agency	1,173	3,422	2.92
U.S. Fish and Wildlife Service	628	1,862	2.96
National Park Service	376	304	0.81
Bureau of Reclamation	53	76	1.43

Source: ResearchGate, August 2015

per the intent of the National Parks Omnibus Management Act.

Shifting the focus of our reporting from an almost exclusive use of the internal NRPS to a balance of NRPS and juried, peer-review journal products is a reasonable next step in the evolution of the I&M program. With an incipient program, it made sense to focus exclusively on the production of internal data summaries that would later support more sophisticated, in-depth analyses. However, now that the I&M program is 15 years old, many networks have sufficient data streams to support rigorous analyses that would result in impactful publications that can inform complex decisions (Machlis and McNutt 2015). As a program, we need to strategically promote such endeavors.

Encouraging our networks to achieve measures of success in new ways (e.g., publishing in the juried literature) invites a re-evaluation of priorities, roles, and functions in the division. This opportunity to re-consider the suite of products and services provided by I&M is also an opportunity to redefine position descriptions that will help achieve a new vision for I&M science credibility and capacity. New priorities may require retooling existing position descriptions to incorporate an NPS research grade evaluation position description customized to the mission of I&M. These positions will merge duties and products that already serve NPS well but will balance management applications with publishing. Pay grades and products commensurate with colleagues in sister agencies who perform comparable work will help with staff retention.

Meeting these challenges is fundamental to the continued success of the I&M program. Overarching themes that will help achieve the intent of the Omnibus Management Act and the I&M mission include increasing credibility of I&M science through external peer review; improving timeliness of information delivery; expanding science capacity via collaboration and community building; and delivering science in ways that are relevant to managers, based on interactions between park staff and I&M staff. Within those themes, there are aspects that can be strengthened to facilitate, incentivize, and promote excellent science that meets current and future needs of the NPS (NPS Advisory Board 2012).

We submit that both organizational and structural changes are needed to achieve these broader goals. This document discusses the requirements for those changes and provides recommendations that will help the program to realize its full potential as a leading provider of place-based science. In the following sections, recommendations are made for specific, achievable actions that will enable I&M to meet the guiding principles and increase its stature as a science program.

Meeting the Principles of Excellent Science

On the whole, the I&M program is already accomplishing many of the seven "Principles of an Excellent I&M Science Program," listed in the previous chapter. This section of the report identifies areas in which I&M should focus its efforts in order to fully achieve the level of excellent science to which we aspire. Each section includes descriptive text and associated recommendations for developing and fostering excellent science. In the paper's final section, the recommendations are organized according to which I&M entity should be responsible for ensuring that they are put into place.

Defining Excellent Science in the NPS Context

In the Introduction, we defined excellent science within the I&M program as "science that is carried out by highly trained and qualified individuals conducting well-designed, relevant, and reproducible investigations that address the complexities and uncertainties of real-world problems facing NPS managers." Speaking most directly to "Excellent Science" principle #1 ("Understand the needs of park managers for natural resource information so that we may identify key questions and objectives, set reasonable monitoring goals, and ensure the usefulness of reporting and communication"), we believe we could improve the program by addressing the following areas.

Asking clear and appropriate questions relevant to NPS

To effectively link science and resource stewardship, the NPS I&M program should focus on clearly stated, cooperatively discussed, and well-defined monitoring questions that are relevant, tied to current needs (i.e., valuable from a resource manager's standpoint), and conveyed in a manner that identifies potential limitations (NPS Advisory Board 2012). Pathways to appropriate management action should be discussed cooperatively by managers and scientists so that the science and potential management actions are mutually satisfactory and beneficial. In addition, mutual awareness of park needs and the capacity of I&M staff should be openly discussed. We must find the intersection of park needs and potential I&M data availability. The more park-relevant questions I&M can address will result in a stronger program and stronger relationships with the park. maintain interest and program support.

I&M staff should also keep aware of upcoming policy and management actions at the park level in order to anticipate delivery of the right science at the right time, which is critical for relevancy. Unfortunately, the availability of science products, which depends on a fairly lengthy process (data checking, analysis, writing, and peer review), does not always coincide with the need for making management or policy decisions. But recognizing this lag up front can help us to anticipate the need for relevant science (Pouyat et al. 2010).

Provide context for place-based science

Placing I&M science and seemingly complex ecological interactions in the context of similar studies or regional or national-level investigations can bolster managers' understanding and provide context for decision makers (Pollard et al. 2014). Putting studies in context not only increases comprehension of complex problems, but often increases understanding of the urgency of management actions by drawing on relevant examples. Providing relevant context in science products can therefore help direct resource allocation, conservation strategies, and adaptation or mitigation goals that are driven by local or regional examples. For example, regional climate change may make habitat islands in parks especially important or may indicate detrimental impacts that cannot be mitigated by management.

The NPS I&M program should strive to be a recognized leader in place-based science such that the program contributes to a deeper understanding and appreciation of its protected places. The I&M program can leverage its science capacity by seeking to ". . . encourage participation of external scientists, scholars, and students in scientific

and scholarly research conducted in national parks, and expand the appropriate use of parks as national laboratories for science" (NPS Science Advisory Board 2012).

The NPS I&M program should also describe how place-based science fits within broader regional, national, and global understandings of processes through the integration of subject literature. Formal consideration of external influences on park-centered ecosystems (*sensu* Hansen et al. 2014) should be considered when developing all I&M scientific products. The NPS Science Advisory Board (2012) clearly articulated that NPS science ". . . must be expanded to encompass a geographic scope beyond park boundaries to larger landscapes and to consider longer time horizons."

Communicating excellent science

In the National Park Service, excellent science is judged in part by its consumers: park superintendents, resource managers, interpreters, and outside science partners. The primary goal of I&M is to synthesize and deliver information on long-term change directly to park resource managers. Science for management necessitates a focus on place-based findings that will be relevant to local users on timely issues. Thus, if scientific information generated by the I&M program is not relevant to the management of park resources, then the program has fallen short of its primary goal. Achieving this goal requires that park managers and science partners provide critical feedback on the usefulness and credibility of I&M products.

Successful science is best achieved when objectives are defined mutually by providers and users of the information. This requires active engagement and two-way communication—parks to networks, network to parks. Network park staff should be encouraged to engage more with I&M science and provide meaningful feedback to improve I&M products for management, and I&M staff must be aware of and sensitive to park issues and needs. Annual technical committee meetings can serve as a forum to elucidate the most pressing issues, and annual park visits by I&M staff should help supplement communication efforts.

Delivering the most pertinent and useful information requires iterative interactions between information providers and information users. By identifying and communicating with end users, the content of reports, including analyses and summaries (e.g., tables and figures), can be tailored to specific needs—and by soliciting and responding to critiques from park staff on I&M products, we will help ensure that I&M information is meaningful and useful. Incorporation of user needs before and during the reporting process increases relevancy of I&M products and will allow the program to grow and improve its core mission. This includes reporting on specific questions related to monitoring data that parks would like answered. A formal process to gather feedback from park staff on the value of I&M products should be introduced (Lovett et al. 2007).

Science communication from I&M staff to the parks is also necessary to relay the timely emergence of relevant findings. To ensure both timeliness and production, regional managers should facilitate critical evaluation of information products, work to eliminate or minimize bureaucratic hurdles, and hold networks and outside divisions accountable for timely products that impact efficiency. All managers should hold employees accountable for credible and timely products. As a strong park partner, I&M must also keep parks abreast of new information by sharing literature and information from conferences and meetings. This exchange can also be accomplished at annual technical committee meetings or park-specific meetings.

Long-term monitoring should not bend to the crisis du jour. However, the I&M program should retain some flexibility to provide value-added information to parks. By adapting to incorporate emerging technologies, assist with future, sometimes unanticipated management needs, or participate in promising collaborative opportunities (Sergeant et al. 2012; Lindenmayer and Likens 2010), we can be responsive to parks without abandoning the core mission of long-term monitoring. For example, I&M should consider how monitoring data can quantify change associated with management actions, catastrophic events (e.g., wildfire), or climate change. In

essence, networks should leverage this aspect of I&M monitoring to answer unanticipated questions (Lovett et al. 2007).

Inquiry-based reporting provides networks with opportunities to demonstrate flexibility and highlight the benefits of monitoring data. Inquiry-based reporting targets use of data to specific questions being asked by park managers. For example, few managers care about every possible climate metric that could be summarized annually. Rather, they may prefer detailed reports or an in-depth analysis on a few metrics that are relevant to a resource issue or relevant to a park or group of parks. Fish, sage grouse, or five-needle pine would all require different analyses to summarize the relevant climate metrics, but focused reporting on a few climate metrics and their influence on resources of concern leverages I&M data, I&M analytical strengths, and needs of park managers.

Finally, tools developed in the central office need to be revisited and revised, with particular attention paid to the usefulness and usability of IRMA and NPSpecies. In concept, these tools are valuable repositories of information, but their structure preempts effective use of them not only by I&M staff, but also by other NPS users (e.g., resource managers, superintendents, interpretation staff, Denver Science Center planners) as well as external users (i.e., external to NPS).

Recommendations for Defining Excellent Science in the NPS Context

- Introduce a formal process for gathering feedback on the value of I&M products to ensure that planned actions and products meet identified management needs. Cooperating with NPS interpretation staff, sharing datasets and resources with collaborators, and publishing in primary literature are examples of ways we can anticipate needs and maintain program relevance to park managers and society.
- Encourage and support inquiry-based reporting that allows networks the flexibility to respond to specific park needs.
- Conduct a review of IRMA and NPSpecies to determine if they can be modified to be more useful and usable, or if they should be dropped altogether. If these databases are to be modified, it is crucial that park resource managers and I&M scientists (consumers of these data) play a major role in the development efforts.

Promoting a "Culture of Science"

Successful monitoring programs rely on the commitment and dedication of employees performing many different roles to generate, interpret, and share relevant information (Sergeant et al. 2012). Open communication among employees, challenging questions, and mutual support are hallmarks of a vibrant "science culture." By building science-based collegiality and collaboration across grade levels and organization boundaries, I&M can promote an NPS "culture of science" that is engaging, dynamic, and inclusive, will stimulate creativity and productivity, and will expand the capacity and strengthen the quality of our science.

The following recommendations for actions and behaviors stem from the concept of collegiality. While examples are provided for leadership roles, these attributes and practices should be demonstrated by all employees. Many of these ideas are paraphrased from Goring and others (2014), Pouyat and others (2010), Lorenzen (2006), Caldwell and others (2014), and Gratton and Erickson (2007), who carefully examined and described how successful science, academic, and business organizations function.

Fostering collegiality

All I&M employees should demonstrate collegial behavior. This includes maintaining professional relationships and relying on interdisciplinary interactions as needed in the pursuit of a common goal. It requires collectively sharing responsibility for workflows and utility of products. Excellent science comes from sustained productivity and completion of complex tasks that have no predefined or obvious path to completion; thus, collaboration with others is often required.

Managing for collegiality and collaboration

Collaborative behavior should start at senior levels, where it is visible to all levels in the organization. It is important to maximize face-to-face communication between organizational levels both internally and externally. Leaders should connect with employees across grade levels and disciplines to encourage collegiality. Informal mentoring can be a useful tool for promoting collaboration, and has shown to be more effective than formal mentoring—primarily because informal mentoring takes place more frequently. Promoting collaborative behavior and community support has been shown to have greater influence on group productivity than rewards or incentives. Rewards and incentives may, however, aid in the retention of productive, collegial employees, and therefore should be considered as part of any attempt to promote a culture of excellent science. Effectiveness can be evaluated through employee interviews.

A workplace with shared workloads and knowledge can occur spontaneously, but managers can also encourage it by sponsoring group events, such as workshops, mini-conferences, meetings, and shared monitoring activities that include park, network, and other scientists, including other networks. At regional and network levels, I&M leadership should also encourage projects and product-driven tasks (such as integration of protocol reporting within networks, cross-network collaboration, and science outreach to park staff) that cross disciplines, networks, and staff levels, resulting in high-impact science products that are broad in scope and generate public interest and awareness of park resources and their condition.

To borrow a phrase from the business community, it takes science to make science, and encouraging cross-network and interdisciplinary project collaboration will help us make the most of the talent and resources we have. These collaborative projects tend to result in partnerships that outlast the initial effort, because as the original task is completed, a network of connectivity remains so that future projects are "jump-started." For such collaborations to be successful, especially among highly focused scientists, interpersonal communication skills are paramount for resolving conflicts. Such "soft" skills can be learned through courses in conflict resolution, but often it takes leaders and a balance of group members that blend personalities and skills.

It follows that complex tasks should be led by both task- and relationship-oriented

leaders with skills in communication and conflict resolution who can establish clear goals at the outset and manage conflict among team members if friction occurs. Leaders should identify roles for team members, ensure they play those roles, and allow latitude for creative ways of achieving goals. This is a departure from more common management style, in which the leader would outline an approach and leave it to the team members to determine roles. This atypical style can prove more effective than traditional styles by reducing friction among team members. Lastly, leaders should assign responsibility but provide sufficient resources and authority for success. The absence of either resources or authority to see a task through can lead to failure.

Additionally, managing for collegiality and collaboration (Gratton and Erickson 2007) requires carefully balancing benefits and pitfalls associated with large groups, virtual communication, member unfamiliarity, and high education levels. Too much of any one of these can result in failed group endeavors and conflict. These "fault lines" can be avoided by breaking up groups that have too much in common.

Expanding science capacity

In order to maintain the NPS's commitments to understanding how park ecosystems function, monitoring resource condition and change, informing decision makers and their decisions, and enriching public appreciation of science and park resources, we must build from our existing intellectual infrastructure and monitoring programs and expand our internal and external science capacity. Of primary importance is the need to recruit, develop, and retain talented NPS scientists and technicians who are actively engaged in NPS science and create a workforce prepared to address the complexities and uncertainties of real-world problems facing the National Park System.

Additionally, I&M should foster relationships with a broad range of scientific investigators and user groups that may include other government research agencies, research university faculty and students, science-based NGOs, and citizen scientists. Cultivating relationships with outside scientists will require strong two-way communication and include the regular exchange of information and ideas among partners. These partnerships should provide opportunities for NPS to participate in coordinated, multidisciplinary research efforts that may not be directly associated with monitoring, but do explore the rich datasets and scientific assets of the NPS (Machlis and McNutt 2015).

Where possible, I&M should also consider opportunities to expand capacity through the use of citizen science (Dickinson et al. 2012). Whether volunteers assist with data collection in the field or crowd-sourcing techniques are applied to datasets over the internet, the NPS should strive to expand opportunities to harness the public's enthusiasm for parks and desire to gain authentic monitoring experiences. Closer to home, creating internal blogs, subgroups across networks, and personnel swaps will build personal relationships and a place-based culture of science.

Maintaining professional skills and institutional credibility

To ensure that I&M scientists maintain their professional skills and credibility, I&M should contribute to the development of a required training curriculum of resources and science staff. NPS law enforcement personnel, administrative staff, and interpreters all attend required training that directly relates to improving their job performance (i.e., that is geared toward career development). However, there is no such required training for science and resources staff—though there's little doubt that achieving success as a resource specialist or scientist in the NPS requires a great degree of specialized knowledge beyond what's learned through education and associated field work. In addition, it is ineffective—and inadvisable—to do science in a vacuum. Knowledge and methodologies are constantly evolving, yet NPS resource and scientific professionals have few established opportunities to ensure that they remain current with those changes.

Incorporating required training specific to science/resources career development—to

include continuing education and conference participation—would not only improve our effectiveness and productivity, but also could help raise the perceived importance of career scientists and resource managers in the NPS. These requirements might include attending a scientific conference relevant to one's field of expertise every two years, and/or taking a college course or similar (like an R course or an Occupancy training) on a regular basis. Opportunities for staff to take sabbaticals or teach a course at a university or field-station opportunities might be offered, along with training on when and how science can be integrated into management processes.

I&M scientists, by virtue of reading, publishing, and interacting professionally with other scientists, will be in good standing to share science that expands on I&M monitoring. All I&M professionals should be science ambassadors capable of communicating the I&M mission and overarching programmatic goals. Over the long term, this will elevate science literacy in the NPS and help actualize the belief of the NPS Science Advisory Board (2012) that "an expanded role for monitoring is an essential component of managing for change."

Strategic vision

IMD leaders are particularly well-positioned to serve as diplomats for the division by promoting visibility at national levels and sharing a strategic vision with I&M employees, policy makers, park superintendents, and other land managers. To meet this goal, I&M leaders should work at the department level to grow its science capacity with other Interior Department agencies. I&M must continue to demonstrate accountability to park managers, the public, and employees by providing strategic vision for products, initiatives and communication with partners that promotes and defends excellent science.

Recommendations for Promoting a "Culture of Science"

- Introduce performance reviews for I&M employees that solicit 360-degree opinions from supervisors, those they supervise, co-workers, and colleagues, including outside collaborators.
- Establish and support collaborative groups for writing peer-reviewed publications by region or topic across networks.
- Develop a sabbatical program in which I&M staff, particularly mid- to late-career employees, are provided the opportunity to pull away from regular duties and work on large, broad-ranging projects, such as advanced data analysis, data organization and management, and projects that will increase program capacity.
- Work with NPS leadership to eliminate or drastically increase network travel ceilings. This will facilitate increased face-to-face interaction with peers, which is essential to promoting a "culture of science."
- Build funding pools specifically to facilitate scientific collaborations at levels beyond the individual network (either within I&M or with USGS, USFWS, USFS, universities, NGOs, etc.) that will strengthen projects and elevate the quality of I&M science.
- Develop a "Science in National Parks" training module to be included in the NPS Fundamentals I training course. The module will identify science as a fundamental tenet of land stewardship in the NPS, outline the organizational structure and responsibilities of NPS science entities in (e.g., NRSS, region, park), present types of questions/conflicts requiring scientific information (e.g., National Environmental Policy Act, Clean Water Act, Endangered Species Act), provide examples of internal and external partnerships where science has been applied, and provide resources (e.g., contact information, websites) to access science information and staff.
- Develop required training for scientists and park resources staff to help maintain scientific knowledge and improve agency credibility.

Identifying and Supporting Excellent Scientists

Historically, scientists have been evaluated largely on their ability to extend knowledge through publishing peer-reviewed articles (Sonnert 1995). Today, scientists in interdisciplinary fields, such as ecology, are evaluated by multiple measures. In addition to authoring peer-reviewed scientific journal articles, those measures include data production and management, analyses, program management and other administrative responsibilities, outreach and education, and co-authorship of technical reports and other publications (Goring et al. 2014). Within the NPS, an excellent scientist must possess the exemplary traits that are common among scientists, such as skills in study design, analysis, and reporting, but also must understand the NPS mission and be able to deliver timely, rigorously reviewed products that are useful to NPS managers.

I&M scientists are those individuals whose positions require the combination of education (typically a graduate degree) and experience needed to develop and implement complex monitoring programs or execute scientific investigations. These responsibilities must be core elements of a position and, as such, require:

- Scientific skills attainable through a combination of experience, training, and graduate-level education (typically an MS or PhD);
- Ability to rigorously apply unbiased scientific methods to design monitoring or other investigations that address questions, problems, and information needs relevant to the mission of the NPS;
- Skills and training in analyzing data, interpreting results, and reporting findings in technical publications (e.g., the NRPS) and other scholarly products;
- Ability to learn and/or collaborate across disciplines to address complex, multi-scaled problems using assessments of observations and empirical evidence; and
- An understanding of the inter-relationships of physical, biological, and social phenomena that affect management of NPS areas.

We suggest three levels of credibility that I&M scientists should strive to attain: (1) credibility with NPS natural resource staff, interpretive staff, and superintendents, (2) credibility with colleagues within I&M, and (3) credibility with peers outside the NPS. To perform optimally, NPS scientists need to deliver products for all of these audiences.

I&M scientists achieve credibility through the professional dissemination of information and through their individual and collaborative involvement in the development of a wide range of scholarly and popular products. Products may include peer-reviewed journal articles and books, NPS technical reports and associated briefs, popular press and newspaper articles, software, interactive maps, photography, films, and other digital media that advance scientific understanding of the National Park System. Other means of promoting professional credibility may include certifications from professional societies (e.g., Wildlife Society, Ecological Society of America) and a presence on professional websites, such as ResearchGate or Google Scholar. Moreover, I&M scientists should establish their credibility in part on their societal contributions or completion of products and/or testing of strategies designed to increase scientific and natural history literacy (*sensu* Tewksbury et al. 2014) and promote civic engagement.

Increasing our presence: Juried publications

I&M scientists invest a great deal of intellectual time writing, editing, and producing technical reports for park managers and resource staff. Many park staff have expressed that this information is of great value to users. Yet sound science, and the credibility of scientists, is often based on having data vetted in the juried, peer-reviewed, scientific literature. This places I&M scientists in a conundrum where investment in the NRPS, with its limited circulation and poor visibility (though with internal value) detracts from their ability to collaborate and publish in the juried, peer-reviewed literature. In addition,

there is an extant perception that publishing in the scientific literature is not our role as NPS scientists, and there is no structure to incentivize and reward those who do publish in peer-reviewed journals.

Excellent science in the NPS context must therefore deliver science that has tangible management applications to the agency and also maintain credibility within the scientific community based on peer-reviewed publications. The I&M program now has large, multi-year data sets and in order to fully leverage the amount of work and tax dollars that went into collecting that information, we must invest time and talent in publishing key findings in the scientific literature while still delivering management-oriented information to resource managers. The effort involved in such endeavorswill advance our collective knowledge, increase the visibility of our science, better support management decisions, and strengthen our overall scientific credibility.

Increasing our presence: Networking

National Park Service scientists participate in professional societies but should also consider ways to increase their online visibility. Online opportunities to post professional accomplishments through professional networks (e.g., LinkedIn) are increasingly common. However, many academic and agency researchers also use science networking sites like Google Scholar Citations and ResearchGate to manage their research and professional profiles and increase the visibility and accessibility of their work. ResearchGate currently has an international membership with over 8 million members.

Establishing an online presence alone may not affect science productivity, but participating in scientific networks like scientific societies provides opportunities to interact with the broader scientific community. Importantly, science networks connect scientists by professional specializations ultimately increasing opportunities for intellectual exchanges and professional collaborations.

Hiring excellent scientists and rewarding excellent science

In order to achieve a strong science program, I&M must work with human resources personnel and the Office of Personnel Management to create a strategy aimed at hiring highly qualified scientists. Hiring practices are inconsistent among regions and it is currently difficult to ensure that well-known scientific measures (e.g., scientific papers, grants) are taken into account during the hiring process. Similarly, the NPS does not reward or recognize scientific achievements in the same manner as other government science agencies. The need to change this situation is acknowledged in the Revisiting Leopold Report: "The NPS should integrate scientific achievement into its evaluation and performance reward systems, providing incentives for scientists and managers who contribute to the advancement of science and stewardship within their park or region" (NPS Advisory Board 2012). To date, these incentives have not been introduced, but they should be in order to prevent intellectual erosion and the loss of additional scientists to other agencies that have a reward system in place.

We recommend the I&M program implement a formal, research grade evaluation process for scientists that allows for promotion based on scientific achievement. This process should include a regular evaluation of the individual's scholarly and innovative contributions, as well as scientific contributions to park management that result in tangible outcomes. Such a process would bring increased credibility to the agency, further demonstrate NPS's commitment to excellent science, and better align the agency with other federal science agencies. Ultimately, this review process would provide guidance for the promotion and retention of high-quality scientists and provide an incentive for scientific productivity in I&M and the greater NPS.

Recommendations for Defining and Supporting Excellent Scientists

- Improve access to journals and scientific literature by acquiring agency-level subscriptions to key journals in the same manner that USGS has accomplished this goal.
- Revamp the hiring process for I&M scientists to allow criteria that better reflect scientific achievement (e.g., knowledge of analytical techniques, publications, collaboration) as benchmarks to get on a hiring cert list, rather than the current benchmarks that are based more on experience in program management (e.g., years of experience, size of budget, people supervised). This new process would consider an applicant's scientific productivity and participation in collaborative, interdisciplinary research, rather than just education and experience, and employ consistent use of subject-matter experts to review applicants and make recommendations to hiring officials.
- Develop a National Park Service research grade evaluation (RGE) process that is specific to the needs of NPS and the Inventory & Monitoring Division and makes pay grades and position descriptions more consistent with those of other successful government agencies. This RGE process would incorporate components of other successful science agencies, such as the U.S. Forest Service and U.S. Geological Survey, but should be customized to fit NPS I&M functions. Not all positions will warrant an RGE evaluation system. Merit promotion will allow us to reward excellent science in a manner that we currently cannot do.
- Establish a committee to determine the rate and kinds of useful science for management, publications, and levels of personal interaction with park staff and collaborators to ensure proper balance between utilitarian science for management, publication in primary literature, and elevation of I&M and NPS credibility in the scientific community. The committee will establish evaluation criteria that consider productivity in core aspects that includes management utility, publication impact points, and interaction with park staff and collaborators.
- Develop a competitive proposal process that allows networks to build on successes already achieved, rather than proposing new projects or monitoring. This will reward those who accomplish excellent science.

Maintaining Our Relevance: Advanced Applications of I&M Data

Monitoring and applied research science

Monitoring, the fundamental basis for the I&M program, is increasingly important for research on natural systems (Lovett et al. 2007; Lindenmayer and Likens 2010). The potential future importance of long-term monitoring is often underappreciated. However, the application of new analytical techniques to long-term datasets (e.g., USGS gaging data, USDA SNOTEL stations, and NOAA's weather stations) consistently reveals some of the most compelling evidence of biological and physical change and aids in understanding of natural systems.

Significantly, monitoring information can be used in multiple ways. Monitoring data often become the basis of natural experiments that test hypotheses or evaluate responses to perturbations occurring at multiple scales. Monitoring data are critical for simulation modeling, testing ecological theory, and evaluating management actions (Lindenmayer and Likens 2010). A strong commitment to monitoring is a hallmark of the I&M program and, accordingly, the benefits of the I&M program to the science of natural systems are only beginning to be realized.

Promote forecasting

Another strength of long-term monitoring is its value for environmental forecasting—an important tool for park managers (Hansen et al. 2014). Given the uncertain future of the National Park System in a changing climate and with increasing population growth, managing ecosystems and species based solely on historic distributions and variability is inappropriate (Baron et al. 2009). Accordingly, I&M should develop qualitative and quantitative forecasting tools to anticipate future change, assess future ecosystem vulnerability, and allow time to mitigate via conservation planning and action. Where possible, we should also build on descriptive, correlative, or trend reporting by adding understanding of causality. This will help to predict the future and provide immediate answers to management questions (e.g., Why did it change, and what can we do about it? Is sagebrush declining due to drought or prescribed fire or conifer encroachment?).

Scaling up

Excellent science goes beyond merely "documenting the decline" (Legg and Nagy 2006); it can also characterize the spatial and temporal extent of the trend, elucidate causes and consequences, and identify drivers to suggest management actions. Syntheses that integrate data across parks, networks, regions, and national monitoring efforts can be crucial for understanding causes and ecological consequences of a trend. These syntheses characterize the spatial extent of change and can identify covariates or predictors. Regional analyses are also essential for understanding the consequences for migratory species or wide-ranging species or ecosystems. I&M leadership could facilitate such broad-scale analyses by supporting regional or national programs that build on common information needs (e.g., adopt the USGS's data-mapping service for the Great Lakes, National Water Information System, allowing others to discover data and partners, which will, in turn, expand the value of studies).

I&M leadership should also encourage the development of cross-network collaborations that leverage the place-based knowledge and breadth of data available across networks. Products could be formalized that incorporate findings across networks monitoring the same vital signs. The goals in this endeavor should be to link concepts to local conditions, place issues in context, and extend the spatial and temporal scope of I&M analyses. Multiple lines of evidence and approaches that cross disciplines can lend credibility to interpretations. For example, multiprotocol reporting using covariates will make more informative products (e.g., reporting climate with vegetation or stream flow data).

Networks as science hubs within NPS

As an active, tangible, and integrated (into parks) science program within NPS, I&M networks have the ability to be effective science hubs that provide a venue for discussing, reviewing, collaborating on, and

planning science in parks. These hubs would have spokes leading to other scientific agencies and partners in the vicinity of the network, as well as to parks and other networks. With long-term monitoring of ecosystem condition as a focus, the structure of networks' technical committees and their meetings provide a perfect venue to move science information forward in parks. At these meetings, long-term monitoring data are disseminated, and the status of resources and science needs can be reviewed and planned for. Using the expertise of I&M data managers, effective data management strategies and structures can be developed that park staff and others can model. These science hubs also should help foster internal (with other NRSS and NPS divisions) and external (e.g., agency, university, non-profits) collaborations and pool opportunities and accessibility to external funding.

Need for science support

Though the I&M program has much to offer in terms of science support, it also has needs for science support. The program has matured from the program development/implementation phase to a science production/delivery phase that needs more quantitative statistical support across the country. An effective way to increase this science capacity would be to bring in quantitative specialists to help networks deal with some of their complex study designs and analyses, and to provide additional support for networks with more limited staff. While the statistical training recommended below will be helpful, experts who specialize in complex monitoring designs are still clearly needed. Outside contractors would be the least desirable solution because they will lack program continuity and understanding of details and nuances of the program. Hiring internal quantitative ecologists or applied statisticians, distributed across networks, is preferred. These staff will have intimacy with the idiosyncrasies of the plethora of protocol study designs, which is crucial to making the best choices. Personnel distribution models might include allocating one quantitative scientist per region to help with all analysis types within that region, or identifying quantitative scientists with different expertise assigned similarly but available for crossover consultations.

Recommendations for Maintaining Our Relevance

- Hire a cadre of quantitative scientists to maximize effectiveness of networks (which vary in levels of staffing, scientific capabilities, and areas of expertise) by providing statistical design and analytical support. The statistics committee should be assigned to define the best approach.
- Develop a Statistics Committee Working Group that is aware of current practices and meets periodically for workshops and knowledge-sharing. This committee would take the lead on providing statistical training.
- Develop a Scientist-in-Residence program at network and/or park level (modeled after the Artist-in-Residence program) in which outside scientists would be enticed to work in a park-based setting.
- Integrate climate analysis into I&M reporting to improve understanding of mechanisms and tipping points of systems.

Conducting Scientific Reviews

Credible science programs/agencies conduct periodic review. We recommend that I&M undergo science reviews at the scientist, network, and national levels.

Scientist reviews

Scientist reviews should be a regular and formal evaluation of the contributions scientists make to managing national parks. This would align the NPS with other federal scientific agencies (e.g., USGS, USFS, and Agricultural Resource Service). Such review would provide guidance for the promotion and retention of high-quality scientists and provide an incentive to maintaining scientific productivity.

Network reviews

Network reviews should focus on specific network or multi-network protocols. We have outlined two possible types of network reviews. The first is an **epistemic review** that focuses on integration of a network's protocols and results for understanding park ecosystems. The second is a **topical review** that focuses on one protocol at a time. These reviews may also bring in other networks or monitoring programs that are conducting similar or complementary monitoring. The network-level reviews will emphasize the specific science associated with a given protocol.

Program review

As was recognized by the Revisiting Leopold committee (NPS Advisory Board 2012), it is essential that the entire I&M program get feedback from non-NPS scientists:

The NPS should establish a standing Science Advisory Board that includes representatives from a range of disciplines within the scientific community. The board would offer external perspectives on science in the parks, provide advice and guidance on science policy, priorities and controversies, and advocate on behalf of science within the agency. The board should be given specific responsibilities and appropriate resources in order to operate effectively."

Recommendations for Conducting Scientific Reviews

- Implement a scientist review process.
- Implement network science reviews.
- Have outside scientists conduct decadal, bird's-eye reviews of the entire I&M program.

Ensuring Appropriate Peer Review

Rigorous peer review is an essential tool to generate and ensure excellence in science. In addition, established peer review processes provide a badge of credibility, signifying quality (if not excellence) in the science product. Indeed, it was concern over the objectivity of internal science that led then-Secretary Babbitt to remove scientists from the NPS in 1993 (Krahe 2012). A National Academy of Sciences evaluation of federal research programs determined that the most efficient way of evaluating federal science programs was through expert or peer review (NAS 1999). Quality science must serve as a foundation for federal policies and regulations and for the management of public lands (GAO 1999).

Rigorous review can catch hidden or unjustified assumptions, omissions, or important related knowledge or issues; misinterpretations of aspects of the literature; and unclear explanations, as well as simple errors of logic or math. That feedback can be used by authors to make a good report/manuscript stellar, or to improve a mediocre or poor manuscript to meet minimum standards. Peer review should be considered a tool to improve science, rather than a hoop to jump through.

There are several reasons why the importance of rigorous review is heightened for I&M scientists. I&M staff are often isolated, with few nearby colleagues available for routine discussions. Access to the current scientific literature is limited. I&M monitors a broad set of vital signs; therefore, staff must have broad understanding of fields outside of their personal specializations and use this knowledge to fully consider the complexities and uncertainties involved with ecological systems. Under the Open Government Act of 2009, I&M is legally required to record the comments of reviewers, as well as the responses and changes made relative to each of those comments.

The I&M program already conducts peer review of science products. However, a more formalized peer-review process will ensure quality in science products at all levels. This process should engage technically qualified I&M, park unit, and university peers, and technical writers for nearly all written products. For scholarly publications, an additional peer-review step will be initiated by the journal, including subject-matter experts at the journal's discretion.

Peer Review Standards

It is the opinion of the Stellar Science Committee that there should be two kinds of peer review for I&M products: an internal peer review performed primarily by I&M and park staff, and an external peer review performed at least in part by outside scientists.

Internal peer review

Internal peer review should be required for any report that includes conclusions, recommendations, or non-routine statistical analyses. Data visualization tools that stand alone should also go through quality assurance and quality control before results are posted to the web.

For a document or dataset to undergo internal peer review, there should already be a peer-reviewed protocol in place that covers the data collection and analyses. Review should then be conducted by a network program manager, park staff, and another I&M scientist from the same or another network. For an initial annual report, an additional review from an external (non-NPS) subject-matter expert is strongly recommended. Subsequent annual reports would not need this external review unless they included substantial changes in analyses or findings.

External peer review

I&M trend reports, status reports based on 5–10 years of data, reports with complicated analyses and conclusions, and "State of the Network" reports should go through an external peer review. These reports should be reviewed by 2–3 subject-matter experts, at least one of whom is external to the I&M program. I&M staff need to publish significant findings in peer-reviewed journals; in this case, the author would follow the review procedures of that particular journal.

Communication products

I&M has shown that communication products outside of traditional scientific reports are incredibly valuable for conveying information about the division's findings and operations to much larger audiences. These types of products include data visualization tools, social media, videos, summary briefs, popular press articles, and park newspapers/interpretive products. Under no circumstances should scientific findings be presented in communication products unless they have already gone through internal or external peer review and a report has been published. Communication products that just entail what an I&M network is doing (e.g., "The Northeast Temperate Network will be monitoring spruce-fir forests in Acadia National Park in 2015" in a brief, or "The Southern Plains Network will head to the Arkansas River today to check on water quality" in a Facebook post) do not need peer review.

It is important to note that there may be some products that warrant additional review by park units, regional program managers, regions, and Washington D.C. offices due to their sensitive nature.

Networks should use their best judgment when deciding how to publish their findings. When there are significant findings to science, the best outlet might be a scientific journal with a follow-up brief that quickly summarizes the information. However, there are many times when an I&M network produces valuable and sound scientific data that would never be published in a scientific journal. Locations of invasive plants in an invasive plant report or an exceedance report for water quality are two examples that provide valuable information to park managers and should be published in the NRR series.

Recommendations for Ensuring Appropriate Peer Review

- Require networks to regularly publish scientific findings for each monitoring program in a peer-reviewed format (both internal and external). (Briefs are not a substitute for peer-reviewed publications and reports. If findings are not peer-reviewed, they are not credible.)
- Produce a short brief (no more than 4 pages) summarizing key elements of publications and trend reports that clearly conveys information to managers after each peer-reviewed, in-depth trend report and journal publication.
- Integrate peer review into and consider it to be part of the regular duties of I&M scientists, rather than a collateral duty that "takes time away from other efforts."

Twenty-Five Recommendations for Fostering Excellent Science

Although every I&M employee will bear some responsibility for the ultimate success of the efforts proposed in this report, the impetus to initiate them will come from leadership at the network, regional, and WASO levels. This section groups the recommendations that have appeared throughout this document according to the appropriate management level at which each recommendation should be implemented. In addition, the Stellar Science Committee ranked each recommendation in order of importance. These recommendations, listed in order of priority, may be found in Appendix A.

Network Level
(Responsibility: Network Program Manager)

1. Introduce a formal process for gathering feedback on the value of I&M products to ensure that planned actions and products meet identified management needs. Cooperating with NPS interpretation staff, sharing datasets and resources with collaborators, and publishing in primary literature are examples of ways we can anticipate needs and maintain program relevance to park managers and society.
2. Integrate climate analysis into I&M reporting to improve understanding of mechanisms and tipping points of systems.
3. Produce a short brief (no more than 4 pages) summarizing key elements of publications and trend reports that clearly conveys information to managers after each peer-reviewed, in-depth trend report and journal publication.
4. Integrate peer review into and consider it to be part of the regular duties of I&M scientists, rather than a collateral duty that "takes time away from other efforts."

Regional Level
(Responsibility: Regional Program Manager)

5. Introduce performance reviews for I&M employees that solicit 360-degree opinions from supervisors, those they supervise, co-workers, and colleagues, including outside collaborators.
6. Establish and support collaborative groups for writing peer-reviewed publications by region or topic across networks.
7. Revamp the hiring process for I&M scientists to allow criteria that better reflect scientific achievement (e.g., knowledge of analytical techniques, publications, collaboration) as benchmarks to get on a hiring cert list, rather than the current benchmarks that are based more on experience in program management (e.g., years of experience, size of budget, people supervised). This new process would consider an applicant's scientific productivity and participation in collaborative, interdisciplinary research, rather than just education and experience, and employ consistent use of subject-matter experts to review applicants and make recommendations to hiring officials.

WASO Level
(Responsibility: IMD Chief, Deputy Chiefs, and Leadership Team)

8. Encourage and support inquiry-based reporting that allows networks the flexibility to respond to specific park needs.
9. Conduct a review of IRMA and NPSpecies to determine if they can be modified to be more useful and usable, or if they should be dropped altogether. If these databases are to be modified, it is crucial that park resource managers and I&M scientists (consumers of these data) play a major role in the development efforts.
10. Work with NPS leadership to eliminate or drastically increase network travel ceilings. This will facilitate increased face-to-face interaction with peers, which is essential to promoting a "culture of science."
11. Develop a sabbatical program in which I&M staff, particularly mid- to late-career employees, are provided the opportunity to pull away from regular duties and work on large, broad-ranging projects, such as advanced data analysis, data organization and management, and projects that will increase program capacity.
12. Build funding pools specifically to facilitate scientific collaborations at levels beyond the individual network (either within I&M or with USGS, USFWS, USFS, universities, NGOs, etc.) that will strengthen projects and elevate the quality of I&M science.
13. Develop required training for scientists and park resources staff to help maintain scientific knowledge and improve agency credibility.
14. Develop a "Science in National Parks" training module to be included in the NPS Fundamentals I training course. The module will identify science as a fundamental tenet of land stewardship in the NPS, outline the organizational structure and responsibilities of NPS science entities in (e.g., NRSS, region, park), present types of questions/conflicts requiring scientific information (e.g., National Environmental Policy Act, Clean Water Act, Endangered Species Act), provide examples of internal and external partnerships where science has been applied, and provide resources (e.g., contact information, websites) to access science information and staff.
15. Improve access to journals and scientific literature by acquiring agency-level subscriptions to key journals in the same manner that USGS has accomplished this goal.
16. Develop a National Park Service research grade evaluation (RGE) process that is specific to the needs of NPS and the Inventory & Monitoring Division and makes pay grades and position descriptions more consistent with those of other successful government agencies. This RGE process would incorporate components of other successful science agencies, such as the U.S. Forest Service and U.S. Geological Survey, but should be customized to fit NPS I&M functions. Not all positions will warrant an RGE evaluation system. Merit promotion will allow us to reward excellent science in a manner that we currently cannot do.
17. Establish a committee to determine the rate and kinds of useful science for management, publications, and levels of personal interaction with park staff and collaborators to ensure proper balance between utilitarian science for management, publication in primary literature, and elevation of I&M and NPS credibility in the scientific community. The committee will establish evaluation criteria that consider productivity in core aspects that includes management utility, publication impact points, and interaction with park staff and collaborators.
18. Develop a competitive proposal process that allows networks to build on successes already achieved, rather than proposing new projects or monitoring. This will reward those who accomplish excellent science.
19. Hire a cadre of quantitative scientists to maximize effectiveness of networks (which vary in levels of staffing, scientific capabilities, and areas of expertise) by providing statistical design and analytical support. The statistics committee should be assigned to define the best approach.

20. Develop a Statistics Committee Working Group that is aware of current practices and meets periodically for workshops and knowledge-sharing. This committee would take the lead on providing statistical training.
21. Develop a Scientist-in-Residence program at network and/or park level (modeled after the Artist-in-Residence program) in which outside scientists would be enticed to work in a park-based setting.
22. Implement a scientist review process.
23. Implement network science reviews.
24. Have outside scientists conduct decadal, bird's-eye reviews of the entire I&M program.
25. Require networks to regularly publish scientific findings for each monitoring program in a peer-reviewed format (both internal and external). (Briefs are not a substitute for peer-reviewed publications and reports. If findings are not peer-reviewed, they are not credible.)

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Appendix A. Recommendations in Priority Order, Based on the Voting of the Seven Committee Members

1. Develop a National Park Service research grade evaluation (RGE) process that is specific to the needs of NPS and the Inventory & Monitoring Division and makes pay grades and position descriptions more consistent with those of other successful government agencies. This RGE process would incorporate components of other successful science agencies, such as the U.S. Forest Service and U.S. Geological Survey, but should be customized to fit NPS I&M functions. Not all positions will warrant an RGE evaluation system. Merit promotion will allow us to reward excellent science in a manner that we currently cannot do.
2. Require networks to regularly publish scientific findings for each monitoring program in a peer-reviewed format (both internal and external). (Briefs are not a substitute for peer-reviewed publications and reports. If findings are not peer-reviewed, they are not credible.)
3. Hire a cadre of quantitative scientists to maximize effectiveness of networks (which vary in levels of staffing, scientific capabilities, and areas of expertise) by providing statistical design and analytical support. The statistics committee should be assigned to define the best approach.
4. Implement a scientist review process.
5. Introduce a formal process for gathering feedback on the value of I&M products to ensure that planned actions and products meet identified management needs. Cooperating with NPS interpretation staff, sharing datasets and resources with collaborators, and publishing in primary literature are examples of ways we can anticipate needs and maintain program relevance to park managers and society.
6. Have outside scientists conduct decadal, bird's-eye reviews of the entire I&M program.
7. Revamp the hiring process for I&M scientists to allow criteria that better reflect scientific achievement (e.g., knowledge of analytical techniques, publications, collaboration) as benchmarks to get on a hiring cert list, rather than the current benchmarks that are based more on experience in program management (e.g., years of experience, size of budget, people supervised). This new process would consider an applicant's scientific productivity and participation in collaborative, interdisciplinary research, rather than just education and experience, and employ consistent use of subject-matter experts to review applicants and make recommendations to hiring officials.
8. Build funding pools specifically to facilitate scientific collaborations at levels beyond the individual network (either within I&M or with USGS, USFWS, USFS, universities, NGOs, etc.) that will strengthen projects and elevate the quality of I&M science.
9. Work with NPS leadership to eliminate or drastically increase network travel ceilings. This will facilitate increased face-to-face interaction with peers, which is essential to promoting a "culture of science."
10. Implement network science reviews.
11. Develop a Statistics Committee Working Group that is aware of current practices and meets periodically for workshops and knowledge-sharing. This committee would take the lead on providing statistical training.
12. Develop a sabbatical program in which I&M staff, particularly mid- to late-career employees, are provided the opportunity to pull away from regular duties and work on large, broad-ranging projects, such as advanced data analysis, data organization and management, and projects that will increase program capacity.
13. Develop a "Science in National Parks" training module to be included in the NPS Fundamentals I training course. The module will identify science as a fundamental tenet of land stewardship in the NPS, outline the organizational structure and responsibilities of NPS science entities in

(e.g., NRSS, region, park), present types of questions/conflicts requiring scientific information (e.g., National Environmental Policy Act, Clean Water Act, Endangered Species Act), provide examples of internal and external partnerships where science has been applied, and provide resources (e.g., contact information, websites) to access science information and staff.

14. Encourage and support inquiry-based reporting that allows networks the flexibility to respond to specific park needs.

15. Establish and support collaborative groups for writing peer-reviewed publications by region or topic across networks.

16. (Tie) Integrate peer review into and consider it to be part of the regular duties of I&M scientists, rather than a collateral duty that "takes time away from other efforts."

16. (Tie) Produce a short brief (no more than 4 pages) summarizing key elements of publications and trend reports that clearly conveys information to managers after each peer-reviewed, in-depth trend report and journal publication.

18. Develop required training for scientists and park resources staff to help maintain scientific knowledge and improve agency credibility.

19. Improve access to journals and scientific literature by acquiring agency-level subscriptions to key journals in the same manner that USGS has accomplished this goal.

20. Conduct a review of IRMA and NPSpecies to determine if they can be modified to be more useful and usable, or if they should be dropped altogether. If these databases are to be modified, it is crucial that park resource managers and I&M scientists (consumers of these data) play a major role in the development efforts.

21. Develop a Scientist-in-Residence program at network and/or park level (modeled after the Artist-in-Residence program) in which outside scientists would be enticed to work in a park-based setting.

22. Introduce performance reviews for I&M employees that solicit 360-degree opinions from supervisors, those they supervise, co-workers, and colleagues, including outside collaborators.

23. Establish a committee to determine the rate and kinds of useful science for management, publications, and levels of personal interaction with park staff and collaborators to ensure proper balance between utilitarian science for management, publication in primary literature, and elevation of I&M and NPS credibility in the scientific community. The committee will establish evaluation criteria that consider productivity in core aspects that includes management utility, publication impact points, and interaction with park staff and collaborators.

24. Develop a competitive proposal process that allows networks to build on successes already achieved, rather than proposing new projects or monitoring. This will reward those who accomplish excellent science.

25. Integrate climate analysis into I&M reporting to improve understanding of mechanisms and tipping points of systems.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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